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Title: Producing Fiber Flax Using Modern Machinery and Field Retting

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Steven J. Knapp

Fiber flax (*Linum usitatissimum* L.) production in the Willamette Valley ended in Oregon around 1957 before newly developed technology and fiber cultivars were available. The purpose of this research was to explore the use of modern methods and new cultivars.

Field studies were conducted to evaluate cultivars and optimum cultural practices that would produce the highest yield and best fiber quality in the Willamette Valley on Woodburn silty clay loam. A study was conducted to assess the winter hardiness of fifty flax cultivars.

The effect of four different pull dates on straw and fiber yield and fiber quality were investigated at two sites in 1995 and 1996. Pulling in stage 2, 3, or 4 resulted in an increase in straw yield over pulling in stage 1 in 1996. No differences were detected in fiber yield or caustic weight loss in response to pull date in either year. An acceptable pulling window is stages 1-3 (range of 900 to 1300 growing degree days). Retting took

13 weeks in both years. Rainfall during the retting period was 10.7 cm in 1995 and 6.9 cm in 1996.

A field study was conducted in 1995 and 1996 to test the effect of three nitrogen (N) levels (50, 75, and 100 kg ha^{-1}) and three fiber flax cultivars (Ariane, Cascade, and Viking) on straw yield. There was a significant increase in yield with increased N levels in 1996. Higher levels of N increased yield in all three cultivars in both years. Lodging of 'Cascade' increased with increased N levels in 1995.

The effect of three planting dates on yield and stand density of Ariane fiber flax were investigated in 1995. The 31 March planting date produced the most retted straw (9704 kg ha^{-1}).

A fall-planted winter cultivar experiment was conducted during 1994-95 and 1995-96. In 1994-95, four varieties (Ariane, Texala, Viking, and Hyslop Cascade) had greater winter survival than Linore, the check variety. Only Linore withstood the second winter.

Producing Fiber Flax Using Modern Machinery and Field Retting

by

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Ralph C. Kennedy, Author

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CONTRIBUTION OF AUTHORS

Dr. Steven J. Knapp was involved in the design, analysis, and writing of each manuscript. Daryl Eherensing was involved in the plot layout and field operations. Ralph C. Kennedy was involved in all facits of the research.

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INTRODUCTION

Problem Definition

Fiber flax production in the Willamette Valley ended in 1957 before modern technology and fiber cultivars were available. Use of modern methods and new cultivars is commonplace in France, The Netherlands, and Belgium.

A number of agronomic factors need to be examined to assess the feasibility of producing fiber flax in Oregon. Planting and harvesting dates, field retting, fertilization using recent cultivars, and the best locations to grow this crop using field retting need to be investigated.

A special jargon is associated with the production of fiber flax. The crop is harvested by pulling the plants from the ground with a machine called a puller. The windrows formed by the puller are allowed to lie in the field to rett. Retting is the controlled rotting of the stems which takes place when fungi penetrate the pith of the stem, populate the cambium and the epidermis, and dissolve the pectic substances around the fiber bundles loosening them from the rest of the stem. The windrows are baled with a round baler and taken to the processing mill where the retted flax straw is scutched. Scutching is the beating of the stems that removes the shives (woody core) from the fiber. The fiber is hackled (combed) which removes the line (long) fiber from the tow (short) fiber. The line fiber is spun into thread and woven into linen. The tow is used to produce paper products such as cigarette paper and currency.

Flax used to be water retted in the Willamette Valley. This practice has been superceded by field retting which relies on alternate sunny and rainy periods during summer-like weather (Sultana, 1988). To take advantage of early summer precipitation before hot and dry conditions prevail, the crop must be pulled in June. Inland areas are not suitable for fiber flax production in France because the weather gets hot and dry too early in summer. Flax is grown along the English Channel where the oceanic influence moderates the temperature and supplies enough moisture for early summer retting. Underretting is a problem when conditions become unseasonably dry in early summer (Van Sumere, 1992).

Hot and dry weather usually prevails by the middle of July in the Willamette Valley. The crop will have to remain on the field until the retting process resumes sometime in the middle of August and continues until September. Harvesting flax late will interfere with fall planting of some cool-season grass seed crops which are grown on much of the potential flax acreage.

The efficacy of modern production methods need to be tested in the Willamette Valley. The effect of nitrogen, cultivars, and growth stage at harvest on yield needs further research. Field retting needs preliminary research to see how it will fit into the grass seed production system.

Literature Review

Concentration will be placed on the agronomy of fiber flax as it is presently grown for the production of high quality field retted fiber. Much of the early research on fiber flax is still applicable today.

Fiber flax cutivars

Fiber flax is traditionally considered a 100 day crop (Dewilde, 1987), but some cultivars are pulled in as little as 85 days (Chin Lu, 1953). Unfortunately, the early maturing cultivars developed before 1960 do not field rett as readily as some of the more recently developed late maturing cultivars (Van Sumere, 1992). They also have a tendency to lodge when planted at high density. The advent of field retting and the limited acreage available for field retting has lead to the development and release of earlier varieties that lend themselves to field retting.

Planting date

Flax is one of the first crops sown in the spring, usually in March but not later than April (Berger, 1965). No definite date can be recommended because the timing is dependent on weather and soil conditions (anonymous, 1961). Easson and Long (1992) concluded that this crop should not be sown before there is a likelihood of soil temperatures over 5°C for several weeks after planting. Plants will survive temperatures of -4°C, so the crop can be planted before the danger of frost has past (Berger, 1965). Planting is accomplished in Europe between 15 March and 15 April in areas bordering the English Channel (Sultana, 1983) and in France and Belgium (Easson and Long, 1992). Some districts in Ireland are planted at this time also, but others are sown in late April or early May (anonymous, 1961).

Various flax experiments have evaluated percent emergence and time before emergence in response to temperature, soil moisture, and planting depth. Greenhouse experiments in Canada show that deep seeding and cool moist soils have a negative effect on percent emergence and time before emergence (O'Connor and Gusta, 1993). Field experiments in N. Ireland show that flax establishment is significantly influenced by weather during the first few weeks after planting (Easson and Long, 1992). Percent emergence is correlated with the number of day degrees over 5°C accumulated during the first three weeks after planting. Poor establishment is the result of earlier planting and leads to variable straw yields. Other research in N. Ireland shows flax planted in late March or early April produces the highest straw yields (Neenam and Devereux, 1973; Easson and Long, 1992). Total fiber yield reaches a peak in late March or early April, and declines with later plantings.

Experiments in France show that height increases following plantings between March and May, but decreases following plantings between May and June (Sultana, 1992). A field experiment in N. Ireland showed that plant height. varied with plantings before 1 May, but decreased with plantings after 1 May (Easson and Long, 1992). Both experiments agree that plant height decreases following late planting dates (after 1-May).

Maturity Stage

The stages of maturity at which fiber flax is pulled are defined by physiological and morphological changes (Chin Lu, 1953). The stages of maturity are indicated by color and defoliation of the stem, capsule color, seed development, color, and capsule dehiscence evidenced by rattling of the bolls (Robinson, 1931; Chin lu, 1953; Dempsey, 1975). Stem color is widely used to judge the stage of maturity (Van Sumere, 1992). The stem color progressively changes from green to yellow starting at the crown. Fiber flax is over-ripe when the stems are tannish yellow.

Dempsey (1975) found that flax should be pulled 30-45 days after flowering, whereas Van Sumere (1992) found that flax should be pulled 5-14 days after flowering. Flax typically matures 900 DD (accumulated over 5°C) after emergence (Sultana, 1992).

Fiber yield typically increases with later pull dates (Robinson, 1931; Chin Lu, 1953; Van Sumere, 1992), but the best quality fiber is obtained with early harvest of this crop even though less fiber is produced (Robinson, 1931). Fiber strength increases when the crop becomes more mature, but the quality declines after the crop reaches yellow to full yellow-ripe maturity because the fiber becomes coarser (Dempsey, 1975; Van Sumere, 1992). Over-ripe flax is difficult to scutch because the shive will not separate from the fiber (Robinson, 1931). The fiber strands may not separate from the fiber bundles in very mature flax even though the shives separate easily (Eyer and Nodder, 1924; Sharma, 1988). High quality flax is fine and elastic, yet strong and free of shive contamination.

Fiber yield using small amounts of flax is quantified by using a reciprocating mechanism to mechanically separate the fiber from the shive (Turner, 1954; Long et al., 1988). The line fiber is separated from the tow by using combs to hackle the fiber (Long et al., 1988). The duration of the scutching (separation) process is used to estimate the degree of retting (Easson, 1988).

The quality of the retted fiber is quantified after scutching through the chemical process known as caustic weight loss (CWL). Sharma and Gilmore (1988) explain two ways of performing CWL on flax fiber. CWL is the most commonly used chemical test because it accurately measures the remaining non-cellulosic components on the fiber (Sharma and Gilmore, 1988). The non-cellulosic components increase as the stem matures (Couchman, 1944). Low CWL represents high quality fiber (Turner, 1954). Archibald (1992) reports a value of 251 mg g^{-1} for high quality flax fiber and 292 mg g^{-1} for low quality flax fiber.

Fiber flax fertility

Local climatic conditions, physical make-up of the soil, and proper cultivation are of primary importance in flax production (Hocking et al., 1989). A clean seedbed, even sowing depth, and steady growth without interruptions caused by diseases, lack of moisture, flooded soils, or competition from weeds are of utmost importance (Lewis, 1943).

Nitrogen levels are extremely important in the production of flax. There are many reports of positive yield responses from applied fertilizers, but the results are inconsistent, especially with N (Hocking et al., 1989). N levels of 20-40 kg ha^{-1} increased yields by an average of five percent over fifty experiments carried out in numerous field trials in Britain (Cooke and Warren, 1959). Higher yields can be obtained with more N, but often without improving net economic returns (Nayital and Singh, 1984).

Too much N can cause a number of problems such as lodging, increased weed competition, loss of fiber quality, and reduced fiber percentage. Excessively high applications of N can cause rank crop growth resulting in lodging and reduced fiber yields (Dempsey, 1975). Nitrogen and phosphorous may stimulate weed growth with deleterious effects on yield where weed control is poor and competition from weeds supresses crop yield (Hocking et al., 1989). Excessively high applications of N reduce fiber quality because of reduced cellulose content and increased lignification (Mikhailova, 1975).

Lodging results from a number of interacting factors. N levels, plant counts, cultivars, and rainfall in the right combination contribute to lodging. No more than the required amount of N should be made available to fiber flax because this crop is prone to lodging (Sultana, 1992). Excessive N tends to produce thin-walled fiber cells with a large lumen, which reduces tensile strength and produces loose and uneven fiber bundles (Berger, 1965). The reduced tensile strength and lack of density affect the overall rigidity of the stem making it more susceptible to external forces such as the extra weight load produced by heavy rains. Heavy rain during rapid stem elongation, usually in June, often causes lodging. Fields in N. Ireland sown in the middle of April suffered from severe lodging as a result of heavy rain in the middle of June (Easson and Long, 1992).

The detrimental effect of N overfertilization on yield comes about when the crop bends over to the point where the puller can no longer reach under the entangled mass to pick it up off the ground (Sultana, 1983). As a result, some of the crop is not pulled at all and the rest clogs the puller up thereby slowing harvest. Lodging causes the fibers to misalign making the extraction of line fiber difficult. Lodged flax is often considered a total loss for this reason.

Increasing the level of N had no significant effect on lodging in N. Ireland, but increasing stand densities increased lodging significantly (Easson and Long, 1992). Alternatively, Maddens (1976) found a significant increase in lodging with increased N levels.

The risk of lodging increases as the stem diameter decreases at higher stand densities. Stand densities of 1400 m^{-2} or higher increased lodging in the Irish experiments (Easson and Long, 1992). There is general agreement that stand densities of 1800-2000 plants m^{-2} are a suitable compromise between high fiber yields and quality (Essautier, 1969; Sultana, 1992).

Some varieties tend to be more lodging resistant than other varieties. Field experiments in France show that lodging susceptibility is correlated with short basal internode length which is associated with a slower elongation rate during early growth (Menoux et al., 1982). Slower elongation rate during the early growth stages results in faster elongation during the pre-bloom period which is when the crop is most susceptible to lodging from rain.

Plant breeders have found that it was easy to select for high yields of quality fiber with weak-strawed cultivars that had a tendency to lodge (Dorst, 1953). Plant breeders now select for varieties with shorter stature and larger stem diameter that can produce high yields of quality fiber without lodging. Improved productivity is obtained mainly through selection of high fiber proportions resulting from an increase in the number of fibrous layers per bundle (Sultana, 1983). Researchers in N. Ireland state that 'Wiera' type French white blossomed cultivars are greatly superior in yield and lodging resistance, while Irish blue blossomed cultivars suffer from lodging (Neenam and

Devereux, 1973). The latest high yielding blue blossomed French cultivars are also lodging resistant (Sultana, 1983). The French cultivars Ariane and Viking are high yielders producing more than 30% total fiber (Sultana, 1983) and are moderately lodging resistant (Sultana, 1992). These cultivars produce as much as 7 metric tons of flax straw and require 75-80 kg ha^{-1} N. Varietal selection should be based on specific considerations including fiber production and quality, lodging and disease resistance, and early development (Sultana, 1988).

Excessive N reduces fiber production and fineness as well. Applications of N, especially at high rates, often result in a lower percentage of fiber by weight or volume as the growth of other stem tissues is stimulated to a greater extent (Milthorpe, 1946). There was a significant difference in fineness depending on the level of N in experiments carried out in Egypt (Gad and El-Farouk, 1978). High application rates of N prolong the vegetative stage delaying cellulose sedimentation during fiber formation; consequently, lignification prevails during hot, dry conditions late in the season (Gad and El-Farouk, 1978).

Moderate applications of N increase straw yield and fiber percentage and improve fiber quality. Straw yield was increased significantly with the application of 30 kg ha^{-1} N (Gad and El-Farouk, 1978). Moderate applications of N increase fiber length (Hamdii et al., 1971). N levels of 30 kg ha^{-1} significantly increased fiber length (Gad and El-Farouk, 1978). Moderate applications of N stimulate the development of phloem and xylem elements resulting in greater cross-sectional area of stem. Moderate applications of N reduce lignin deposition. The application of 15-30 kg ha^{-1} N improved fiber quality by decreasing lignification and increasing the cellulose content of the fiber (Mikhailova, 1975). Straw yield and fiber percentage are increased because of increased length of the stem, better cortical development, and reduced lignification.

Soils considered low in available N (< 0.3%) usually produce the largest average increase in total crop yield in response to N application (Cooke and Warren, 1959). Low N level soils responded with a 280 kg ha^{-1} increase in yield, whereas soils with high levels of available N gave only a 100 kg increase in yield (Cooke and Warren, 1959).

On the other end of the spectrum, N deficiency is also troublesome. N deficient plants are stunted, upright, and thin stemmed. The leaves are small, erect, and pale green; the plants defoliate prematurely from the base of the stem. Few tillers and capsules are produced, and the capsules tend to ripen prematurely (Wallace, 1961).

No critical nutrient levels are found in the literature despite numerous experiments that investigate yield responses of flax to wide ranges of N supply (Hocking et al., 1989). There was no definitive relationship between N uptake of flax plants and yield data in the British Isles (Lewis, 1943). Flax removed 50 kg ha^{-1} N from the soil in India (Dastur and Bhatt, 1965). An average range of 45-67 kg ha^{-1} of N was removed from the soil in several European countries (Lewis, 1943). In France, for example, a crop that yields 7000 kg ha^{-1} of retted flax straw with seed removes an average of 40 kg ha^{-1} N from the soil (Sultana, 1983).

There is general agreement that high yields are obtained with moderate applications of N (Hocking et al., 1989). Recommendations are usually in the range of 30-40 kg ha^{-1} N. Gros (1967) recommends this range for flax grown in France. Similarly, Gad and El-Farouk (1978) recommend 30 kg ha^{-1} N for flax grown in India. Sultana (1992) recommends 75-80 kg ha^{-1} N for high yielding lodging resistant varieties grown at higher densities (1800-2000 plants m^{-2}).

Total available soil N must be considered when figuring out the amount of N to apply. It is advisable not to plant fiber flax for the first time where mineralizable N is too high or after recent application of manure where the undecomposed organic matter (OM) is still present in the soil (Sultana, 1992). The total available N exceeds the demand of the crop in this case and lodging can occur. It is best to apply organic manure such as farmyard manure to the preceding crop (Berger, 1965). It is advisable to test the soil for total available N to a depth of 30 cm in climates where precipitation exceeds evaporation and adjust the N application accordingly when manure has been applied recently or a leguminous cover crop is grown preceding fiber flax. However, fifty percent of the mineralizable nitrogen is available the first year and fifty percent of the remainder is available the second year and every year thereafter making it difficult to estimate the actual N available to the crop.

The most valuable field trials relate responses of flax to applied nutrients according to soil characteristics, soil test results, and environmental parameters because they allow for careful extrapolation to similar sites (Hocking et al., 1989)

CHAPTER I

THE EFFECTS OF NITROGEN AND MATURITY STAGE ON FIELD RETTING AND YIELDS OF FIBER FLAX

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Abstract

Flax (*Linum usitatissimum* L.) is grown in mild maritime climates as a source of fiber for linens and other woven and nonwoven products. This crop was hand pulled and water retted in the first half of this century in Oregon. Several aspects of the flax industry have changed since linen grade flax was last produced on a large scale in the US: most flax is field retted, water retting is seldom used, and planting and harvesting machinery and cultivars have changed dramatically. Our objectives were to assess (i) the effect of maturity stage on the yield and field retting of a fiber flax cultivar Ariane and (ii) the effect of nitrogen fertilization rate on the straw and fiber yields of three fiber flax cultivars (Ariane, Cascade, and Viking). A mechanical puller was used to harvest four growth stages of Ariane in 1995 and 1996. Maturity stage (pull date) had no effect on yield or caustic weight loss of the fiber, but did affect fiber quality. Shives were separated from the fibers of retted straw using a mechanical scutcher. Shives were easily separated from fibers from the first three growth stages. However, the fourth maturity stage was more difficult to scutch. The crop reached maturity in 96 days in 1995 and 107 days in 1996 and maintained pull (harvest) ripeness for 21 days in 1995 and 27 days in 1996. The harvest window was estimated to span 900 to 1300 growing degree days. Windrows were inverted once or twice with a mechanical turner to accelerate retting. The straw was fully retted in 13 weeks in both years with 10.7 cm of rain in 1995 and 6.9 cm of rain in 1996. Field retting can be done in northwestern Oregon and produces linen quality fiber; however, the length of the field retting process delays the planting of subsequent crops.

Additional Index Words: *Linum usitatissimum* L., linen, tow, oilseed flax, flaxseed, scutching.

Introduction

Flax is grown primarily as a source of oil in temperate regions of the world (Dewilde, 1987) and as a source of 'linen grade' fiber in mild temperate maritime climates typified by northern France, Belgium, the Netherlands, and western Oregon. Most of the linen grade fiber is presently produced in W. Europe. Although the morphology of 'oil' and 'fiber' flax cultivars differs, they are both sources of oil, seed meal, fiber, and shive.

Fiber flax was produced in western Oregon through the late fifties. The crop was pulled (harvested) by hand, a tedious and difficult process (Dempsey, 1975). Harvesting was mechanized in the 1920's (Hurst, 1953). Flax was water retted by submerging straw shocks (bundles) in water tanks (Van Sumere, 1992). Mechanical harvesters (pullers and turners) invented in the US (Sultana, 1992a) were rapidly adopted in Europe in the mid-sixties and ushered in field retting. These changes ironically paralleled the collapse of the US fiber flax industry because of the development of low cost synthetic fibers and the high cost of processing flax straw.

Much has changed since the collapse of the US fiber flax industry. Fiber flax is field retted in the principal growing regions and is seldom if ever water retted because of the high cost and the water pollution caused by the effluent from the process. Planting and harvesting machinery have eliminated much of the hand labor associated with producing the crop and modern cultivars have stronger straw and shorter stature (Dempsey, 1975).

The experiments reported in this paper were conducted to assess the feasibility of producing fiber flax in Oregon using modern machinery and cultivars and field retting.

Although oilseed flax can be successfully produced in a wide range of environments, fiber flax has more specific environmental needs for optimal growth and field retting. The crop requires cool conditions for optimal long fiber production, essentially because plant height decreases as temperature increases (Berger, 1969; Sultana, 1992a).

Retting is a process whereby bacterial and fungal organisms degrade the pectins and other cell wall components of the straw (Van Sumere, 1992). Field retting proceeds most rapidly and effectively with warm temperatures and rainy weather (typical range of temperatures and moisture levels that promote microbial growth) and alternating sunny days (Sultana, 1988). The coastal low countries of northwestern Europe along the English Channel have the climate necessary for successfully field retting flax in most years, e.g., sporadic summer rain, warm temperatures, and a sufficient number of DD (~900 DD accumulated over 5°C) to mature the crop before the onset of hot and dry weather (Sultana, 1992a). Poor retting is a problem when the weather is dry (Van Sumere, 1992). Retted straws are processed by mechanical scutching, a process where the shives are separated from the long and short fibers (Sultana, 1992b).. The long fibers are used to produce linen, while the short fibers are used in blended woven and in non-woven products (Franck, 1992). When the straw is insufficiently retted, the shives are difficult to separate from the fibers (Dempsey, 1975).

Typically, straw and fiber yields increase and fiber quality decreases as the maturity of the crop increases (Robinson, 1931; Van Sumere, 1992). The best fiber is usually produced by harvesting the green-ripe stage (Robinson, 1931). Many subjective criteria are used to judge fiber quality: length, luster, color, softness, and feel (Turner, 1954). Laboratory standards have not been developed to measure flax fiber quality, nor are there any formal market standards or orders, and laboratory tests are not necessarily always strongly correlated with the subjective criteria which, in the end, decide the fate of flax in the marketplace (Archibald, 1992).

Caustic weight loss (CWL) has been used to estimate the content of non-cellulosic components of flax straw (Sharma and Gilmore, 1988). These components increase as the crop matures (Couchman, 1944) (CWL decreases as the non-cellulosic fraction decreases). CWL is affected by cultivar, retting, and growth stage (Turner, 1954). Turner (1954) reported a CWL range of 200 mg g^{-1} for water retted to 360 mg g^{-1} for unretted flax. CWL estimates for field retted flax ranged from 237 to 260 mg g^{-1}. Archibald (1992) reported an association between fiber quality and CWL, but that laboratory tests are often not strongly correlated with subjective fiber quality. Samples with high spinning quality fell on the low end of the CWL scale (251 mg g^{-1}), whereas samples with low spinning quality fell on the high end of the CWL scale (292 mg g^{-1}). Archibald (1992) found that chemical tests must be used in conjunction with subjective evaluations of the fiber by expert flax graders to predict spinning quality. Turner (1954) found no correlation between CWL and growth stage in predicting spinning quality. Archibald (1992) reported an association, but did not report a positive correlation between CWL and spinning quality. Robinson (1931) and Van Sumere (1992) reported a that fiber quality decreased when flax reached the over-ripe stage. Correlations between CWL and assorted fiber quality variables, some of which are qualitative, is still uncertain.

Nitrogen (N) fertilization rates greatly affect fiber yield and quality (Hocking et al., 1989). Sultana (1992a) recommended N fertilization rates of 75-80 kg ha^{-1} for maximum yield with lodging resistant cultivars grown at high densities (1800-2000 plants m^{-2}); however, lodging often increases with increased N and can reduce yields (Dempsey, 1975; Sultana, 1983). Easson and Long (1992) reported increased lodging with plant densities greater than 1400 m^{-2} for some cultivars.

Oregon has an excellent climate for growing fiber flax cultivars, but contemporary production practices and field retting have not been tested in Oregon or the US. We describe a series of experiments geared towards reintroducing fiber flax production to northwestern Oregon. Our objectives were to assess (i) the effect of maturity stage on the yield and field retting of a fiber flax cultivar Ariane and (ii) the effect of N rate on the straw and fiber yields of three fiber flax cultivars (Ariane, Cascade, and Viking).

Materials And Methods

Maturity Stage Experiment

The fiber flax cultivar Ariane was grown in yield trials at Hyslop Farm near Corvallis, Oregon in 1995 and Van Leeuwen Farm near Halsey, Oregon in 1996. Both farms are located in the Willamette Valley (45°N, 123°20'W). The soils at both sites were Woodburn series, fine-silty, mixed, mesic, Aquultic Agrixerols. We used randomized complete block experiment design with four replications in both years, with four maturity stage treatments: early yellow-ripe (yellow from the base of stem up to the mid-point of the stem), yellow-ripe (yellow from the mid-point to the three-quarter point of the stem), full yellow-ripe (yellow from the base to the neck of the stem), and over-ripe (tan-yellow from the base to the tip of the stem, a green tint may still be apparent on the neck). Treatments (maturity stages) were randomly assigned to plots.

The field sites were plowed with a moldboard plow in the fall of each year. A winter cover crop of crimson clover (*Trifolium incarnatum* L.) was plowed under in the spring of 1994 at the Hyslop site. An orchard grass (*Dactylis glomerata* L.) crop was plowed under in the fall of 1995 at the Van Leeuwen site. Total available N test to a depth of 30 cm revealed that there was 5 kg ha^{-1} of N available in the spring of 1995 at the Hyslop site. Seveny-five kg ha^{-1} of N was applied by spreading urea before preparing the seedbeds. The 1995 seedbed was prepared using a pulvomulcher and roller. The 1996 seedbed was prepared by disk harrowing, field cultivating, split rolling, and drag tooth harrowing. Seed was planted on 31 March in 1995 and 25 March in 1996 with a French 'Nodet' planting drill. This drill 'underground broadcasts' seed on 7.6 cm centers by distributing seed on a splatter plate below the drop plate in the center of the shoe (instead of falling directly into the furrow), thereby creating a banded row 6 cm wide. We used seeding rates of 118 kg ha^{-1} in 1995 and 170 kg ha^{-1} in 1996. The seeding rate differences partly stemmed from 1000-seed weight differences between 1995 (5.70 g) and 1996 (5.16 g) seed lots and from 1995 stand densities below the target of 2000 plants m^{-2}. Stand densities were estimated post-emergence in May by randomly placing a 0.1 m^{-2} quadrat in each plot and counting the number of plants within the quadrat. Stand density and percent emergence were calculated for each plot. We applied 0.25 kg a.i. ha^{-1} of MCPA amine ([4-chloro-2methylphenoxy] acetic acid) and sethoxydim (2-[1-

(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) in a tank mix with a 0.25% non-ionic surfactant when the flax was 5-10 cm tall.

The plots were pulled at 10-14 day intervals as a function of growth stage. A 1.4 x 15.0 m strip was mechanically pulled from the center of each plot in 1995 using a Depoortere self-propelled puller. One x 1 m strips were hand pulled from the center of each plot in 1996. Plots were field retted until the straws in the windrows were tan-silver-grey to silver-grey throughout. Windrows were mechanically turned twice using a Depoortere self-propelled turner in 1995 and hand turned twice in 1996. The retted straw was weighed.

Samples of 70 undamaged stems were randomly selected from each plot for caustic weight loss and scutching tests. Samples were oven dried for 4 hrs. at 38°C before weighing. After the seed capsules were removed, each sample was scutched using a laboratory scutcher until no further shive could be removed. Our laboratory scale scutcher which was similar to the one described by Long et al. (1988) differed from the scutcher described by Long et al. (1988) in two ways. We used one slotted blade moving between two stationary slotted blades instead of two slotted blades moving between two sets of stationary blades, and blade reciprocating frequency of 185 min^{-1} instead of 324 min^{-1}. Samples were scutched for 4 to 8 min. Scutching was stopped when shives could no longer be separated from fiber. Scutching time and fiber weight were recorded. CWL was estimated from a 3 g sample taken from the middle 20 cm of the scutched fiber sample. The sample was chopped into 2 to 3 cm lengths before processing. Weights of processed and unprocessed samples were recorded.

The SAS (1992) mixed linear models procedure PROC MIXED was used to perform analyses with maturity stage as a fixed effect and block, year, growth stage by year, and error as random effects. The linear model for the experiment was

$$y_{ijk} = \mu + b_i + y_j + g_k + gy_{jk} + e_{ijk}$$

where μ is the overall mean, b_i is the effect of the *i*th block, y_j is the effect of the *j*th year, g_k is the effect of the *k*th maturity stage, gy_{jk} is the effect of the interaction between the *j*th year and the *k*th maturity stage, and e_{ijk} is the random error. Block (σ_b^2), year (σ_y^2), growth stage by year (σ_{gy}^2), and error (σ_e^2) variance components were estimated using the restricted maximum likelihood (REML) procedure of SAS (1992). The null hypotheses $H_0{:}\sigma_b^2 = 0$ $H_0{:}\sigma_y^2 = 0$ and $H_0{:}\sigma_{gy}^2 = 0$ were tested using z-statistics (SAS, 1992). The hypothesis of no maturity stage effect was tested using F-statistics: $F = M_g \,/\, M_e$ for analyses of individual years and $F = M_g \,/\, M_{gy}$ for the analysis across years, where M_g is the maturity stage mean square, M_e is the error mean square, and M_{gy} is the maturity stage by year mean square estimated using mixed model procedures (SAS, 1992). Mean differences between maturity stages were tested using pairwise linear contrasts and broad prediction space standard errors (SAS, 1992).

National Oceanic and Atmospheric Administration (NOAA) weather data for the last 30 years at Hyslop Farm near Corvallis were used to calculate the cumulative growing degree days (DD) between our earliest planting date and latest harvest date. DD were calculated by averaging the daily high and low temperatures above a threshold of 5°C. We recorded the dates Ariane reached each of the four growth stages in 1995 and 1996 and plotted growing degrees days against dates for both years and against the mean of 30 years. The growth stage points were plotted to show the relationship between the phenology of the crop and growing degree days.

Cultivar by Nitrogen Fertilization Rate Experiment

This experiment was conducted at Hyslop Farm in 1995 and 1996. We used randomized complete blocks experiment designs with four replications in both years and tested nine treatments: factorial combinations of three cultivars (Ariane, Cascade, and Viking) and three N rates (50, 75, and 100 kg ha^{-1}). The nitrogen source was urea.

Except as noted, fields were prepared and planted and the crop was pulled, turned, and retted as previously described. A winter cover crop of crimson clover (*Trifolium incarnatum* L.) was plowed under in the spring of 1994. We applied 50, 75, and 100 kg ha^{-1} of N using Urea. The 1996 seedbed was prepared using a 'Lely' Rotera and roller. The nurseries were planted on 3 March in 1995 and 25 March in 1996. Plots were 1.4 x 15.0 m in 1995 and 1.48 x 7.5 m in 1996.

Plots were mechanically pulled as previously described, turned once, and harvested on 5 July 1995 and 8 July 1996. The three cultivars ranged from yellow-ripe to fully yellow-ripe at harvest. Plots were retted for 8 wks. before weighing the field-dried retted straw.

The SAS (1981) general linear models procedure PROC GLM was used to perform analyses with cultivar (C), nitrogen fertilizer rate (N), year (Y), C x N, C x N x Y, and block as fixed effects. The linear and quadratic effects of N were estimated using orthogonal polynomial contrasts (SAS, 1981): $\mu_{50} - \mu_{100}$ for the linear effect of N and $\mu_{75} - \frac{\mu_{50} + \mu_{100}}{2}$ for the quadratic effect of N, where μ_{50}, μ_{75}, and μ_{100} are the means for 50, 75, and 100 kg ha^{-1} N, respectively. Mean differences between cultivars were tested using least significant differences.

Results

Maturity Stage Experiment

The block, year, and maturity stage by year variance components for straw and fiber yield and CWL were not significantly different from 0. The effect of maturity stage across years was not significant on straw yield ($p = 0.2$), fiber yield ($p = 0.15$), or CWL ($p = 0.24$). Maturity stage had a significant effect on straw yield ($p = 0.02$) in 1996, and there were significant differences between growth stages for straw and fiber yield in 1996 (Table 1.1). Straw yield increased as maturity increased through the full yellow- ripe stage. Fiber yield was not affected by maturity stage (Table 1.1).

CWL mean for Ariane across years was 296 mg g^{-1} (Table 1.1). Although our CWL estimates fell in the range of flax fiber samples reported to have low spinning quality (Archibald, 1992), the other subjective quality characteristics of the samples we harvested from the first three growth stages were excellent: the root ends were straight, the stems were whitish-yellow, the retted straws were ~1 meter long, and the fiber was fine and strong and had a high luster, characteristics typifying high quality linen grade flax (Turner, 1954). The most advanced maturity stage (over-ripe) produced a coarser fiber

Table 1.1. Straw and fiber yields, and caustic weight losses (CWLs) for the cultivar Ariane harvested at four maturity stages in Corvallis in 1995 and Halsey, Oregon in 1996.

Maturity stage	1995 Havest date	1995 Straw yield	1995 Fiber yield	1995 CWL	1996 Havest date	1996 Straw yield	1996 Fiber yield	1996 CWL	Mean Havest date	Mean Straw yield	Mean Fiber yield	Mean CWL
		kg ha^{-1}	kg ha^{-1}	mg g^{-1}		kg ha^{-1}	kg ha^{-1}	mg g^{-1}		kg ha^{-1}	kg ha^{-1}	mg g^{-1}
Early yellow-ripe (1)	4 July	12809	4637	287	9 July	9470a†	3959a	294	1	11139	4298	290
Yellow-ripe (2)	13 July	13114	4798	300	17 July	10085ab	4145ab	305	2	11600	4471	303
Full yellow-ripe (3)	25 July	13723	5064	285	5 August	10655c	4499c	303	3	12189	4782	294
Over-ripe (4)	3 August	13827	5070	291	19 August	10365bc	4414bc	306	4	12096	4742	298

† Means followed by different letters are significantly different at 0.05 probability level.

and was more difficult to scutch than the three earlier maturity stages. Shives were easily separated from fibers from the three early growth stages. These samples took three to four minutes to scutch in our laboratory scutcher. Samples from the fully ripe growth stage took ~2 min. longer to scutch than the earlier growth stages. Our findings confirm those of Robinson (1931) who reported greater scutching difficulty with full yellow-ripe flax straws than with straws from earlier growth stages.

Ariane reached the early yellow-ripe maturity stage, typically the earliest stage harvested, in 873 DD in 1995 and 928 DD in 1996 (Fig. 1.1). The mean DD to this stage across the two years (~900 DD) was similar to the mean reported by Sultana (1992) for other late maturing cultivars. Ariane maintained optimal harvest (pull) ripeness for high quality fiber production through the full yellow-ripe stage. Ariane reached this stage in 1221 DD in 1995 and 1385 DD in 1996; thus, the mean harvest window across the two years was 900 to 1300 DD (Fig. 1.1). Ariane reached harvest maturity in 96 days in 1995 and 107 days in 1996, which is slightly longer than the mean harvest maturities of 85 and 101 days reported by Chin Lu (1953) for Cascade. The crop maintained pull ripeness for 21 days in 1995 and 27 days in 1996. One cm of rainfall in the middle of July may have lengthened the pulling window in 1996, whereas very dry July weather may have shortened the pulling window in 1995. Using the 30 year heat accumulation mean, the predicted optimum planting and early and late harvest dates on fiber flax in western Oregon were 8 April, 14 July, and 10 August, respectively.

The crop required 13 weeks to fully rett in both years. The rate of retting through July and August was strongly correlated with rainfall in both years. Dew was an insignificant source of moisture throughout the summer and did promote retting until

Stages of 'Ariane' fiber flax maturity at different pull dates according to DD accumulated after 1-Mar.

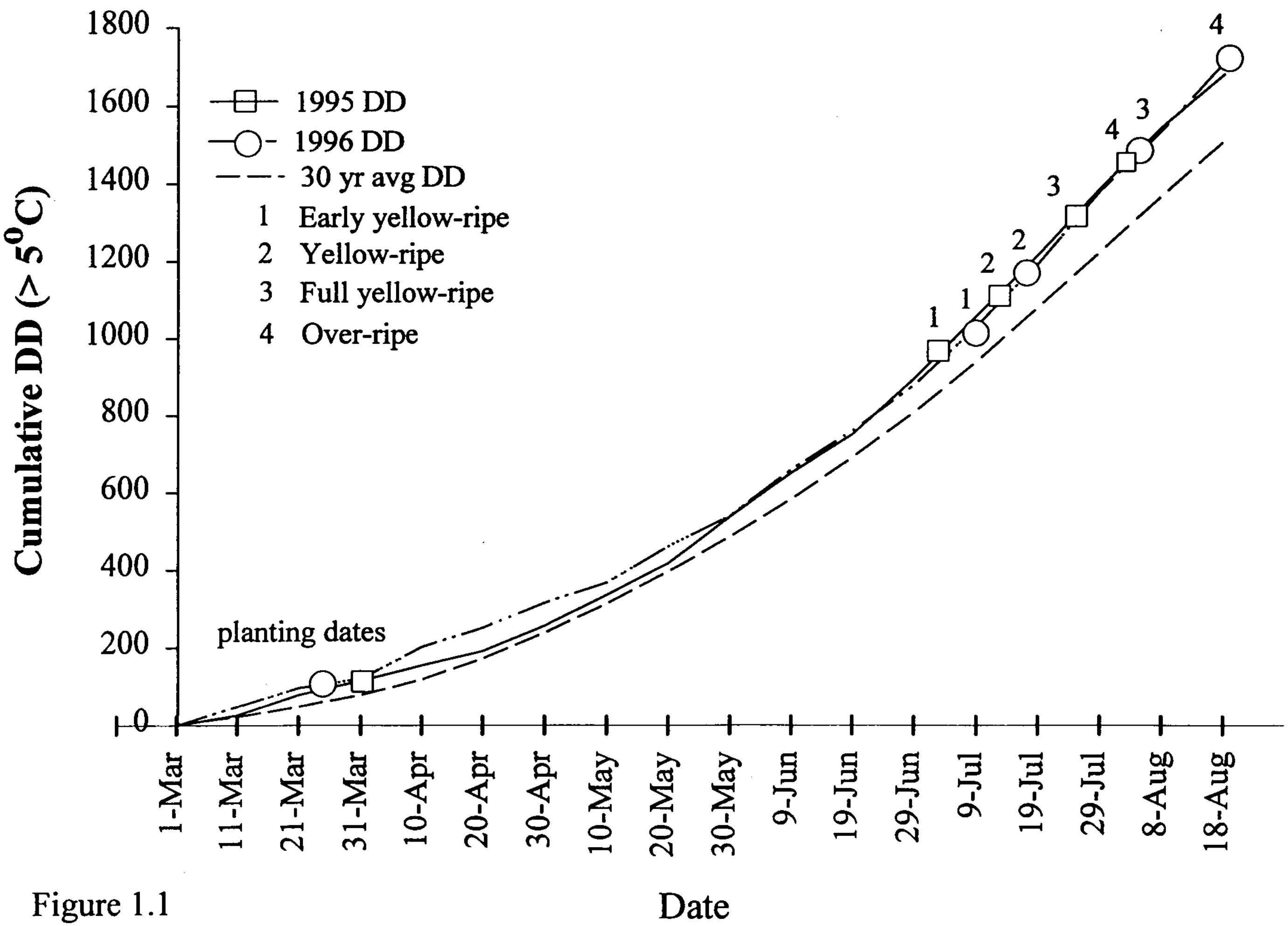

Figure 1.1

Fig. 1.1. Maturity stages of Ariane fiber flax maturity in the Willamette Valley at different pull dates as a function of growing degree days (DD) accumulated after 1-Mar. The four stages are early yellow-ripe (1), yellow-ripe (2), full yellow-ripe (3), and over-ripe (4).

September when temperatures and dew points decreased. The total rainfall throughout the retting period was 10.7 cm in 1995 and 6.9 cm in 1996. Although there was less rain for retting in 1996, we had more dew moisture in late August and early September as a consequence of lower night time temperatures. Palleson (1995) showed that 10.7 cm of rain was needed to obtain well-retted fiber in Denmark. The 30 year mean rainfall for Corvallis between 1-Jul and 30-Sep is 7.4 cm.

Cultivar by Nitrogen Fertilization Rate Experiment

The effect of N was not significant in 1995 ($p = 0.18$) and significant in 1996 ($p = 0.0003$) (Table 1.2). There was a significant N x year interaction ($p = 0.005$). The C x N interaction effect was not significant in either year ($p = 0.35$) in 1995 and 0.76 in 1996). The C x N interaction effect was significant ($p = 0.0001$). The linear effect of N was non-

Table 1.2. Straw yield of three fiber flax cultivars and three nitrogen fertilization rates in 1995 and 1996 at Corvallis, Oregon.

	N, kg ha^{-1}				N, kg ha^{-1}			
Cultivar	50	75	100	Mean	50	75	100	Mean
	kg ha^{-1}							
	1995 Yield				1996 Yield			
Ariane	5159	5190	4831	5060a†	6065	7540	8087	7230a
Cascade	7804	7124	7489	7472b	7590	8820	8894	8435b
Viking	6853	7172	7783	7269b	6943	7794	8122	7620a
Mean	6606	6495	6701		6866	8051	8368	

† Means followed by different letters are significantly different at 0.05 probability level.

significant in 1995 ($p = 0.09$) and significant in 1996 ($p < 0.0001$). The yield plateau between 75 and 100 kg ha^{-1} N levels in 1995 might have been caused to the release of N from the 1994 crimson clover crop. The quadratic effect of N was non-significant in both years ($p = 0.45$ in 1995 and 0.11 in 1996).

The effects of cultivars were significant in both years ($p < 0.0001$ in 1995 and $p = 0.003$ in 1996) (Table 1.2). The ranks of the cultivar means did not change across years. Cascde and Viking produced substantially more straw than Ariane (Table 1.2). Cascade produced slightly more straw than Viking, but was taller and tended to lodge with increased N in 1995. The lodging observed for Cascade was 10% for 50, 50% for 75, and 70% for 100 kg ha^{-1} of N in 1995 and 30% for 50, 0% for 75, and 0 % for 100 kg ha^{-1} of N in 1996; thus, the lodging problem was inconsistent across years with increased N. Viking and Ariane did not lodge in either year. These cultivars are newer and shorter and have stronger stems than Cascade.

Discussion

Post-harvest weather conditions were an insignificant factor when flax was grown in Oregon in the early part of the twentieth century because the crop was hauled to facilities for water retting soon after harvest, thereby freeing the field for the next crop by late August or early September. Water retting is no longer economically or environmentally practical, and the industry has shifted to field retting by virtue of the development of equipment for straw harvesting and turning to facilitate field handling and retting. The production of high quality fiber flax for some uses, e.g., linens, requires a thoroughly retted product; however, uses are being developed for whole unretted flax straw. This product can be produced more rapidly and cheaply than retted straw. The fiber flax cultivars we tested matured at the start of our summer dry season and took 13 weeks to rett in both years. Our annual rainfall should be sufficient in most years to produce fully retted fiber for high end uses. The crop must be retted, baled, and removed from the field before the onset of the wet season, usually in October. The greatest margin of safety can be had by harvesting the early yellow-ripe stage. The fiber yields of this stage are often less, but the fiber quality is high and farmers can get an early start on retting.

Delay in the removal of the flax crop because of the extended time needed for field retting in the Willamette Valley puts significant time pressure on farmers who are trying to rotate fields out of flax and into grasses, e.g., the ryegrasses (*Lolium*) or fescues (*Festuca*). With the flax crop retting in the field, farmers cannot prepare seedbeds for grasses until the crop is finally retted and baled in September. Fall rains which normally begin in the first half of October can delay tillage operations until the following spring.

The development of an earlier maturing and faster retting cultivar would speed up the production of the crop. Late spring rains can sometimes be exploited by early cultivars to speed retting before dry summer weather halts the process. The separation of the cuticular layer from the cortex may be accelerated by slightly crushing the stem. We found that stems retted more rapidly where they were pressed between belts when they were initially pulled. Retting might be sped up even further by using a conditioning crusher, such as those used to condition hay. Some pullers (harvesters) have root end crushers which could be redesigned to crush the entire stem.

Lodging was a problem for Cascade in our tests. Dempsey (1975) reported increased lodging with increased N; however, he tested older cultivars which are taller and have weaker stems than most modern cultivars. Cultivars released in recent years are typically shorter in stature than Cascade and tend to have stronger stems. Part of our lodging problem in 1995 was created by heavy rain when the crop was flowering in mid-June. Easson and Long (1992) reported lodging caused by heavy rain Northern Ireland, but N had no effect on lodging. Easson and Long (1992) reported that stand densities greater than 1400 m^{-2} increased the lodging of shorter and stronger stemmed cultivars such as Ariane and Viking. Our stand densities were 800 m^{-2} . We did not study the effect of stand density on straw or fiber yield or lodging, but this might be worthwhile, particulary in view of the extremely high densities and seeding rates used to produce fiber flax.

References

Archibald, L.B. 1992. Quality in flax fibre. p. 297-309. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M Publ., Belfast.

Couchman, J.F. 1944. The effect of straw maturity on the chemical composition of flax straw and fibre. J. Counc. Sci. Ind. Res. (Aust.) 17:139-143.

Dempsey, J.M. 1975. Flax. p. 3-45. *In* Fiber crops. Univ. Presses of Florida, Gainesville.

Dewilde, B. 1987. Flax in Flanders throughout the centuries. Lanoo, Tielt, Belgium.

Dorst, J.C. 1953. Does the present trend to select for resistance to lodging in flax involve dangers of a loss in quality ?. Euphytica 2: 96-100.

Easson, D.L., and F.N.L. Long. 1992. The effect of time of sowing, seed rate and nitrogen level on the fibre yield and quality of flax (*Linum usitatissimum* L.). Irish J. of Agric. and Food Res. 31:163-172.

Franck, R.R., 1992. The history and present position of linen. p. 1-9. *In* H.S. Shekhar Sharma (ed.) The biology and processing of flax. M Publications, Belfast.

Hocking, P.J., P.J. Randall, and A. Pinkerton. 1989. Mineral nutrition of linseed and fiber flax. Adv. in Agron., 41:221-296.

Long, F.N.J., D.L. Easson, and J.P. Frost. 1988. Laboratory determination of fibre content and quality in flax. Record of Agric. Res. 36:27-36.

Palleson, B.E., 1995. The quality of combine-harvested fibre flax for industrial purposes depends on the degree of retting. Industr. Crops Products 5:61-85.

Robinson, B.B. 1931. The time to harvest fiber flax. USDA Tech. Bull. 236. U.S. Gov. Print. Office, Washington, D.C.

SAS Institute. 1981. SAS user's guide: Statistics. 1982 ed. SAS Institute, Inc., Cary, NC.

SAS. 1992. SAS technical report P-229. p.289-370. *In* SAS/STAT software: changes and enhancements. Release 6.07. SAS, Cary, North Carolina.

Sharma, H.S.S., and C. Gilmore. 1988. An improved method for determining the caustic weight loss of flax fibre. J. Text. Inst. 80:285-286.

Sultana, C. 1983. The cultivation of fibre flax. Outlook on Agric. 12:104-110.

Sultana, C. 1992a. Growing and harvesting of flax. p. 83-109. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Sultana, C. 1992b. Scutching of retted-flax straw. p. 261-274. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Turner, A.J. 1954. Quality in flax. Linen Industry Research Institute, Lampeg, Lisburn, Co. Antrim, N. Ireland.

Van Sumere, C.F. 1992. Retting of flax with special reference to enzyme-retting. p. 157-198. *In* H.S.S. Sharma and C.F. Van Sumere (ed.) The biology and processing of flax. M Publ., Belfast.

CHAPTER II

PLANTING DATE EFFECTS ON FIBER FLAX YIELD COMPONENTS

Abstract

Without irrigation fiber flax (*Linum usitatissimum* L.), an annual fiber crop, must become established in western Oregon before precipitation begins to wain in late April. This study was conducted to determine the optimum planting window for fiber flax in the Pacific marine climate of the Willamette Valley of Oregon, USA using a contemporary flax production system. The effects of planting date on yield, and stand density of flax were investigated at Corvallis, OR, on Woodburn silty clay loam (fine-silty, mixed, mesic, Aquultic Agrixerol). In 1995, three planting dates with the flax cultivar Ariane were planted on 3 March, 31 March, and 25 April. The 31 March planting date produced 9704 kg ha^{-1} field dried straw yield compared to 7334 and 4675 kg ha^{-1} for the 3 March and 25 April planting dates, respectively. Plant height decreased from 69 cm for the 3 March planting date to 58 cm for the 25 April planting date.

Flax should be sown from the last week of March through the first week of April in order to obtain the highest yields in the Willamette Valley. Acceptable yields are likely to be obtained with early March plantings when weather and soil conditions are favorable. Mid to late April plantings are likely to produce short plants and low yields.

Additional Index Words: *Linum usitatissimum* L., fiber flax, linseed.

Introduction

Fiber flax requires abundant moisture and cool weather during growth to maximize fiber yield and quality. Cloudy days later in the growth cycle conserve moisture and promote the maturation of seed and production of high quality fiber.

To take advantage of early season rains and cool growing conditions flax is one of the first crops sown in the spring, usually in March but not later than April (Berger, 1965). No definite date can be recommended because the timing is dependent on weather and soil conditions (anon., 1961). Easson and Long (1992) conclude that this crop should not be sown before there is a likelihood of soil temperatures over 5°C for several weeks after planting. Plants will survive a few degrees of frost so early planting is possible (Berger, 1965). Planting is accomplished in Europe between 15 March and 15 April in areas bordering the English Channel (Sultana, 1983). France and Belgium are examples of this planting window (Easson and Long, 1992a). Early districts in Ireland are planted at this time also, but later districts are sown in late April or early May (anon., 1961).

Various flax experiments have evaluated percent emergence and time before emergence in response to temperature, soil moisture, and planting depth. Greenhouse experiments in Canada show that deep seeding and cool moist soils (below 5°C) have a negative effect on percent emergence and time before emergence (O'Connor and Gusta, 1993). Field experiments in N. Ireland show that flax establishment is significantly influenced by weather during the first few weeks after planting (Easson and Long, 1992). Percent emergence was correlated with the number of growing degree days (DD) over 5°C during the first three weeks after planting. Patchy establishment was the result of earlier planting and led to reductions in straw yields (Easson and Long, 1992).

Other research in N. Ireland shows that straw and fiber yields reach a peak from late March or early April plantings and decline with later plantings (Neenam and Devereux, 1973; Easson and Long, 1992).

The length of the line fiber increases as flax plant height increases which produces more line fiber of higher quality. Experimental results involving plant height have produced differing results. Field experiments in France showed that height increased from plantings between March and May, but decreased from plantings between May and June (Sultana, 1992). A field experiment in N. Ireland showed that plant height varied with plantings before 1 May, but decreased with plantings after 1-May (Easson and Long, 1992a). Both experiments agree that plant height decreases with late planting dates (after 1 May).

The climate in the Willamette Valley is similar to that of Belgium, Normandy, and some districts in N. Ireland except that rain continues into the summer in the European countries. Planting dates between the middle of March and the middle of April should optimize straw and fiber yields by taking advantage of spring moisture and soil warming. The likelihood of favorable weather conditions over the first few weeks after planting should promote early growth. An experiment was conducted in 1995 to test the effect of different planting dates on the yield, stand density, and height of fiber flax in the Willamette Valley.

Materials And Methods

The experiment was conducted in 1995 at Hyslop Farm, Corvallis, OR, USA (45°N, 123°20'W). The Willamette Valley experiences a Pacific Marine mid-latitude climate with mild winters, cool moist springs, and hot dry summers. The experimental site contains Woodburn series soil, a fine-silty, mixed, mesic, aquultic agrixerol. We used a randomized complete block experimental design with four complete blocks (replications).

Treatments (planting dates) were randomly assigned to plots. We used 'SAS' GLM procedure for randomized block experiment to test the hypothesis of no effect of planting date on yield against the hypothesis that there was at least one difference in yield (SAS, 1981). The significance of mean differences between planting dates was tested using least significant differences. All statistical inferences were made at the 0.05 probability level of significance.

National Oceanic and Atmospheric Administration (NOAA) weather data for the last 30 years at Hyslop Farm near Corvallis were used to calculate the cumulative DD between planting and emergence. DD were calculated by averaging the daily high and low temperatures above a threshold of 5°C. We recorded the dates Ariane emerged and plotted yield and stand density against DD. Yield and stand density were plotted to show how heat accumulation affects days to emergence, stand density, and yield. Precipitation data for 1995 at Hyslop Farm were used to claculate rainfall following planting.

The plots were planted approximately three weeks apart, depending on favorable weather and soil conditions. The actual dates used in the analysis were 3 March, 31 March, and 25 April. Plots were plowed with a moldboard plow and then prepared with a pulvomulcher with a horizontal shaft to rotate L-shaped blades followed by a cage-type roller which created a fine, firm seedbed 8-10 cm in depth. Total available N test to a depth of 30 cm revealed that there was 5 kg ha^{-1} of N available in the spring of 1995. Nitrogen was applied at the rate of 75 kg ha^{-1} in the form of urea before seedbed preparation. A 3 m wide French 'Nodet' drill with 7.6 cm centers was used for planting. Unlike conventional drills that plant single rows this drill uses broadcasting shoes creating a banded row 6 cm wide and 2-4 cm deep. Each plot consisted of one 3 m drill pass 15 m long. Weeds were controlled with the application of 0.25 kg a.i. ha^{-1} each of MCPA amine ([4-chloro-2methylphenoxy] acetic acid) and sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) in a tank mix with 0.25% non-ionic surfactant applied postemergence when the flax was 5-10 cm tall.

The French fiber flax cultivar Ariane was used on all of the experimental plots. An average of 2070 seeds m^{-2} were planted resulting from a planting rate of 118 kg ha^{-1} of 5.7 g per thousand seed weight seed.

Plant counts were taken postemergence in May by randomly placing a 0.1 m^{-2} quadrat in each plot and counting the number of plants within the quadrat. Stand density and percent emergence were calculated for each plot. A single plant height measurement was taken randomly before harvest of each plot.

Plots were pulled when the crop was full yellow-ripe. Pulling was performed with a Belgian self-propelled, 'Depoortere', puller which pulled a 1.4 m wide strip forming a single windrow. One pass was taken lengthwise down the center of the drill width creating a 1.4 x 15 m plot of 21 m^{-2}.

Windrows were allowed to rett until the undersides were silver-gray in color and were then turned with a 'Depoortere', self-propelled turning machine. Retting continued until the windrows were mostly silver-gray throughout. The field-dried straw was weighed.

Results

Yield was significantly influenced by planting date in this experiment ($p = 0.0004$). The 31 March planting produced a significantly higher yield than the other two planting dates (Table 2.1).

Table 2.1. Effect of planting date on Ariane fiber flax yield components at Hyslop Field Laboratory, Corvallis, Oregon in 1995.

Planting date	Stand density	Emergence	Emergence	Height	Straw yield
	plants m^{-2}	%	days	cm	kg ha^{-1}
3 March	140a†	6.8	14	68.6a	7334.5a
31 March	902b	43.6	11	65.4a	9704.6b
25 April	562c	27.2	9	57.8b	4675.26c

† Mean yields followed by a different letter are significantly different at the 0.05 probability level (LSD=1437.9).

The yield of the first and third plantings were 76 and 48% of the second planting, respectively. Stand density was significantly influenced by planting date ($p = 0.0003$). The 31 March planting produced a higher stand density than the other two planting dates (Table 2.1). The first and third plantings produced 85 and 38% lower densities than the second planting, respectively. In addition, it took longer for the early and late plantings to emerge (Table 2.1). Finally, plant height was significantly influenced by planting date ($p = < 0.05$). The 3 March and 31 March plantings produced taller plants than the 25

April planting date (Table 2.1). The third planting produced 5 and 12% shorter plants than the first two plantings, respectively.

Discussion

Both stand density and straw yield were affected by planting date. Early planting produced low stand densities (Fig. 2.1), but moderate yields were still obtained because the plants compensated by producing thicker stems (Fig. 2.2). Late planting produced high stand densities (Fig. 2.1), but the crop produced low yields (Fig. 2.2).

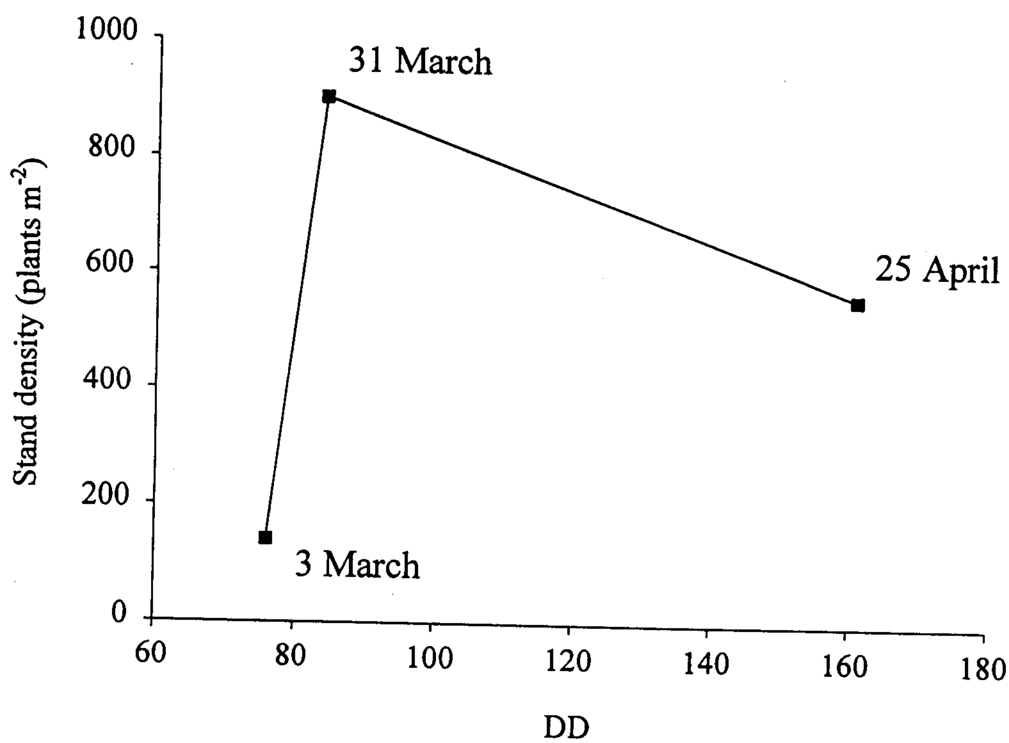

Figure 2.1. Effect of DD (accumulated over 5°C) during three weeks after planting on stand density of Ariane at Hyslop Field Laboratory in 1995.

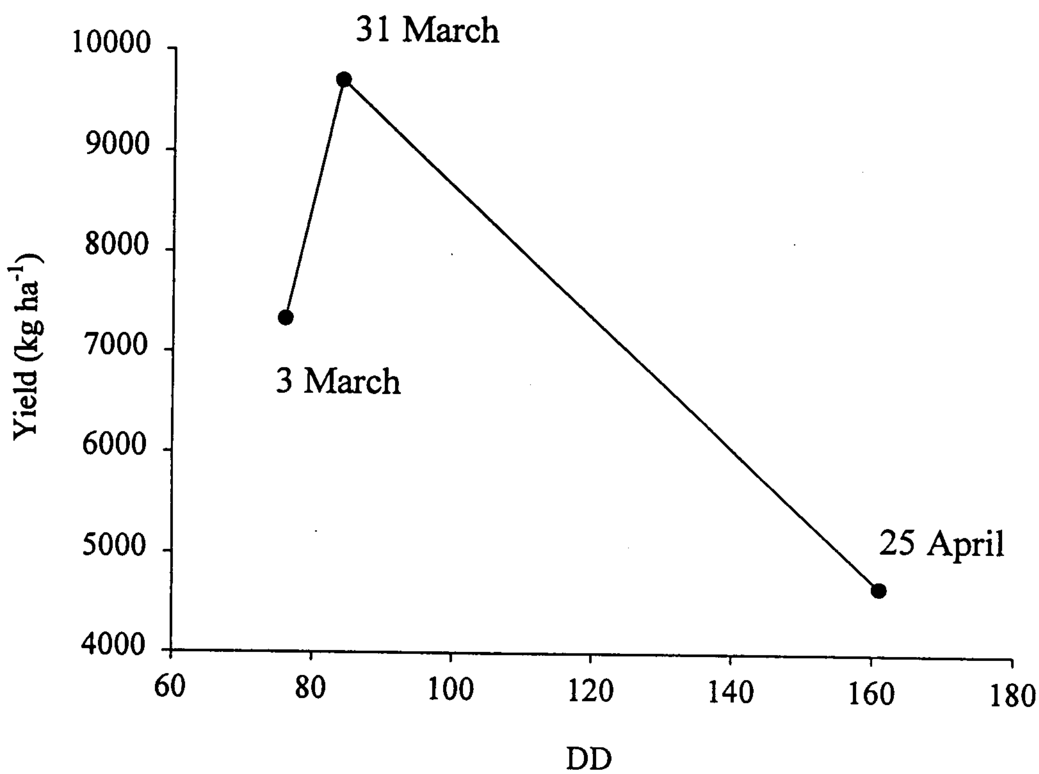

Figure 2.2. Effect of DD (accumulated over 5°C) during three weeks after planting on straw yield of Ariane at Hyslop Field Laboratory in 1995.

Timely planting produced moderate stand densities, and high yields. Reduced soil moisture increased stand densities between 3 March and 31 March. However, much drier soil following planting on 25 April was the most likely cause of reduced yields and stand densities (Table 2.2). Our results agree with the results of Easson and Long (1992) who found that higher heat accumulations following planting increased straw yields.

Table 2.2. Weather conditions three weeks after flax planting at Hyslop Field Laboratory, Corvallis, Oregon in 1995.

	planting date		
	3 March	31 March	25 April
	rain		
	mm		
Week 1	42.2	8.4	40.9
Week 2	40.4	62.2	12.5
Week 3	36.3	24.4	18.3
Total	118.9	95.0	71.6
	DD (above 5°C)		
Week 1	12.8	39.4	50.6
Week 2	39.2	25.0	52.5
Week 3	24.2	20.0	57.5
Total	76.1	84.4	160.6

Conclusion

We concluded that flax should be sown from the last week of March through the first week in April to obtain optimum yields and stand densities. This planting window is similar to areas along the English Channel in Belgium, France, The Netherlands, and some districts in N Ireland. With favorable weather and soil conditions it is possible to plant during March because moderate to high yields can also be obtained during this period. Poor emergence due to compaction from heavy rainfall during March makes planting more risky. If weather and soil conditions are not favorable during March and early April then lower yields can still be obtained from late April plantings. It is better to consider planting a different crop if planting cannot be accomplished before May.

References

anonymous. 1961. The growing and harvesting of flax.. Ministry of Agriculture Leaflet 94. Stormont, Belfast.

Berger, J. 1969. Flax. p. 209-215. *In* The world's major fibre crops their cultivation and manuring. Centre D'Etude de l'Azote, Zurich.

Easson, D.L., and F.N.L. Long. 1992. The effect of time of sowing, seed rate and nitrogen level on the fibre yield and quality of flax (*Linum usitatissimum* L.). Irish J. of Agric. and Food Res. 31:163-172.

Neenam, M., and J. Devereux. 1973. Some recent researches on the growing of fibre flax. Sci. Proc., Royal Dublin Soc. B:201-221.

O'Connor, B.J., and L.V. Gusta. 1994. Effect of low temperature and seeding depth on the germination and emergence of seven flax (*Linum usitatissimum* L.) cultivars. Can. J. Plant Sci. 74:247-253.

SAS Institute. 1981. SAS user's guide: Statistics. 1982 ed. SAS Institute, Inc., Cary, NC.

Sultana, C. 1983. The cultivation of fibre flax. Outlook on Agric. 12:104-110.

Sultana, C. 1992. Growing and harvesting of flax. p. 83-109. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

CHAPTER III

FLAX WINTER HARDINESS TRIAL

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Abstract

The demand for short fiber is increasing on a world-wide basis. Flax (Linum usitatissimum L.) is an annual fiber crop that could be grown as an overwintering crop in mid-latitude marine climates. We conducted a preliminary fall-planted winter cultivar experiment during the winters of 1994-95 and 1995-96 in the mid-latitude Pacific marine climate of the Willamette Valley of Oregon, USA with mild winters, cool moist springs, and hot dry summers. Fifty flax cultivars chosen by height, Fusarium wilt resistance, type, and geographical location, plus one check cultivar Linore that withstands temperatures as low as -17°C were planted in 1.5 m, one row plots of 50 seeds each. Eighteen of the cultivars including the check cultivar withstood temperatures at or below -4°C for a total of 5 days during the first winter resulting in 44-87% survival. Four cultivars had greater survival than Linore which exhibited a 63% rate of survival: Ariane with 87%, Texala with 81%, Viking with 68%, and Hyslop Cascade with 66%. Four cultivars produced measurable biomass in the one row plots: Hollandia with 243.4 g, Linore with 220.8 g, Emeraude (PI # 524374) with 189.3 g, and PI # 523316 with 116.6 g. Only Linore withstood 10 days at or below -4°C during the second winter.

Additional Index Words: Winter hardy flax cultivar; Annual fiber crop; Fall-planted winter hardy flax cultivar.

Introduction

The production of short fiber for blended fabrics, paper pulp production, and other industrial purposes does not require the long (line) fiber produced from traditionally early spring planted crops (Pallesen, 1995). Fall planted flax is a possible source of short fiber where the winters are mild enough to allow the crop to overwinter.

Demand for short fiber continues to increase as spinning technology advances to a point where different types of fiber can be more easily combined (Franck, 1992). Demand for other sources of pulp for paper and industrial composites is also increasing as the world-wide timber supply dwindles. Development of pulp mill technology that will accept many different fiber sources without retooling will be a likely response to the decrease in timber supply. New sources of fiber must be developed to satisfy the world-wide demand for short fiber.

Fiber flax could be grown as an overwintering crop in the mild climate of the Willamette Valley to produce short fiber which would be chopped up for these uses. Research was initiated to find a winter flax cultivar after the second world war, but the demand for other fiber sources disappeared as the need for fiber decreased after the war in addition to the expansion of the timber industry. Today, fiber flax is reemerging as one way of increasing fiber production abroad as well as in the USA. Fouilloux (1988) considers the possibility of producing 'winter flax' in Europe.

A number of flax cultivars were tested for cold tolerance as a part of a fiber flax research program at the Oregon State Agricultural Station during the post-war period (Calhoun, 1964, Oregon Agricultural Experiment Station, Corvallis, Oregon, USA, unpublished). The flax cultivars were planted on September 29, 1949 by Don Fischler of the USDA, ARS in a nursery at Hyslop Farm in Corvallis, Oregon. The temperature dipped to a record low of -17°C on 31 January, 1950. A small number of individual plants survived. Oregon 48-W, later named Linore, was selected from this group and the seed was increased and fall-planted every year from 1950 to 1961. 'Linore' survived 47 days below -4°C over twelve winters. Linore is a blue flowered oil seed variety producing multiple branches but not obtaining the height of fiber varieties chosen for maximum fiber production. Linore serves as a baseline for future winter cultivar trials.

Plant breeders have developed many cultivars of flax over the last seventy years which has led to increased yields of straw, seed, fiber, and greater resistance to disease and lodging (Dempsey, 1972). The Germplasm Repository Information Network (GRIN) maintains a catalogue of many flax cultivars which can be searched for by name, country of origin, date of release, morphological characteristics, and disease resistance. However, no data on yield or cold tolerance are available.

The objective of this research was to evaluate a large number of flax cultivars for winter hardiness and to assess their branching characteristics and yield capabilities. We wanted to see if tall fiber cultivars could overwinter and produce upright axillary branches in the spring. Furthermore, we wanted to test a diverse range of cultivars representing different morphological characteristics and geographical origins to see if a particular set of characteristics would be preferable.

Materials And Methods

We planted experiments during two winters between 1994 and 1996 at Hyslop farm to test the winter hardiness of fifty flax cultivars compared to Linore at one location in the Willamette Valley of Oregon, USA (45°N, 123°20'W). The Willamette Valley experiences a Pacific Marine mid-latitude climate with mild winters, cool moist springs, and hot dry summers. The experimental site contains Woodburn series soil, a fine-silty, mixed, mesic, Aquultic Agrixerol. Plots were planted on 15 September in 1994 and 2 October in 1995. The trial consisted of 50 nonreplicated 1.5 m one row plots with four replicated check plots, totaling 54 plots in all. Fifty seeds of each cultivar were planted approximately 1-2 cm deep in each plot using a one row push type planter with disk openers and a press wheel set to drop the seeds over a 1.5 m distance.

The cultivars were evaluated by taking stand counts after the danger of a hard freeze (at or below -4°C) had passed in late March. The number of remaining plants in each plot was divided by the number of initial emergents, then converted to percent survival. The survival rates of the three check plots were averaged to obtain the check survival percentage. Branching was subjectively rated on a scale of 0-10 with 10 equaling a low degree of branching. Average height of the surviving cultivars was also recorded at the same time. Cultivars were ranked according to their percentage survival. Field-dried biomass was recorded in grams for each plot at the time of harvest in early July. The flax cultivars used in this experiment were selected from the GRIN database and cultivars maintained at Hyslop Farm, Corvallis, OR. Plant introductions were supplied by Jerry F. Miller (USDA, Fargo, North Dakota). We desired a tall upright cultivar for maximum short fiber production exhibiting resistance to *Fusarium* wilt, a common problem in the Willamette Valley. Cultivars were chosen accordingly using five sets of criteria: (i) release date and height (fiber and oil seed types released in 1978 or later with a height of 76 cm or more) (ii) type (fiber) (iii) type, height, and Fusarium wilt resistance (0 = resistant), (fiber types more than 81 cm tall with wilt resistance less than 5) (iv) type, wilt resistance, and wide range of countries (fiber types with wilt resistance less than 5 from

Belgium, Canada, France, Germany, Hungary, Korea, Netherlands, N. Ireland, Pakistan, Poland, and Russia) (v) cultivars available at Hyslop Farm, Department of Crop and Soil Science, Corvallis, Oregon.

Enough seed was available for a nonreplicated experiment so statistical analyses were not performed.

Results and Discussion

Although the mean low temperatures experienced in 1994-95 and 1995-96 were comparable, the extremes were different, resulting in different outcomes. Fig. 3.1 shows the daily minimum temperatures at ground level at Hyslop Farm between 1 October and 30 March for both years. Average minimum daily temperatures of 3 and 4°C during the first and second year, respectively, were both slightly above the 10 year average of 2°C. Temperatures during the first winter were representative of Oregon's winter weather with 5 days at or above 10°C and 5 days at or below -4°C. Average daily minimum temperatures were more extreme during the second winter, swinging widely from mild to cold with 11 days at or above 10°C and 10 days at or below -4°C.

Unusual weather patterns accompanied the most extreme cold snap during both winters. In 1994-95, the cold weather on 13, 14, and 15 February was preceded by a 10 cm deep snow which covered all but the tips of the plants and burned the lower leaves off of many plants. In 1995-96, the freezing weather from 30 January to 4 February was accompanied by desiccating winds. The cold snap was immediately followed by freezing

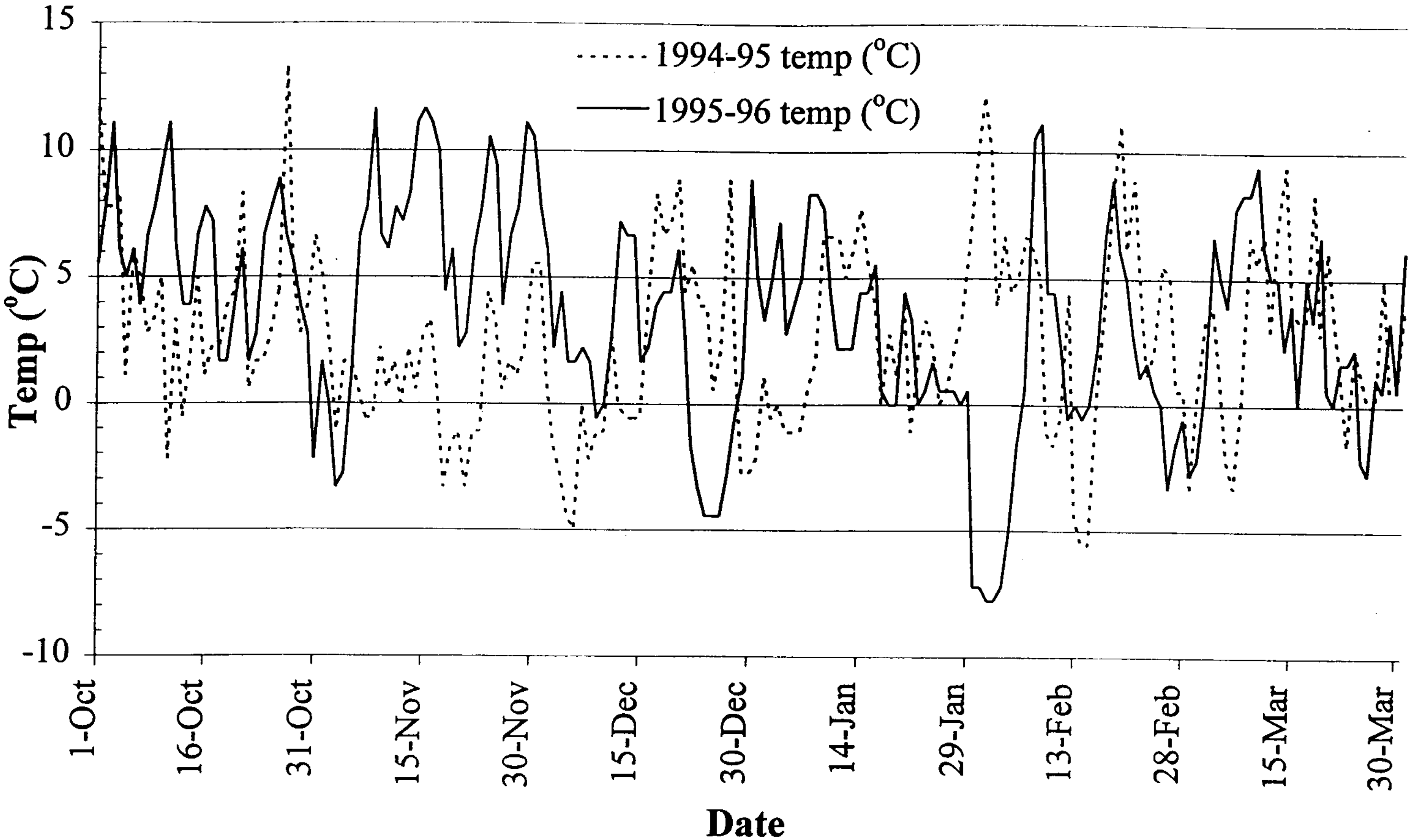

Figure 3.1

Fig. 3.1. Daily minimum temperatures at ground level during two winters at Hyslop Field Laboratory.

rain and then followed by record breaking rainfall. The worst flood in over 30 years covered all of the plots for more than a week.

A great number of plants survived the first winter, but 10 cultivars succumbed to the cold weather and the snow (Table 3.1). Only Linore survived the second winter. During 1994-95, four cultivars outsurvived Linore which exhibited an average survival rate of 63%: Ariane with 87%, Texala with 81%, Viking with 68%, and Hyslop Cascade with 66%. Eighteen cultivars exhibited 44% or greater survival (Table 3.2). Linore withstood 10 days at or below -4°C during the second winter exhibiting a survival rate of 14%.

The check and three of the seventeen top cultivars produced enough biomass to give meaningful yield results. The other 14 cultivars with high survival rates were outcompeted by weeds by the time of harvest in early July. Table 3.2 shows that three cultivars compared very favorably to Linore in total biomass. We believe the other 14 cultivars could have performed similarly in multiple row plots with less competition from other species.

Cultivars from cool marine climates had better survival than cultivars from continental climates. Cultivars from France, followed by The Netherlands, Oregon, USA, and N. Ireland outperformed cultivars from all the other countries. Several cultivars from eastern Europe and Russia also ranked in the top eighteen.

The branching characteristics of the top 18 ranged from 3 to 10. Branching results from a pattern of midwinter decumbency followed by late winter branch initiation exhibited by hardy varieties (Calhoun, 1964, Oregon Agricultural Experiment Station, unpublished). Seven cultivars with minimal branching (8 to 10) outsurvived 2 other cultivars with higher degrees of branching. Generally, cultivars with higher degrees of

Table 3.1. Winter survival of 51 flax concessions at Hyslop Field Laboratory, Corvallis, Oregon.

		survival		branching‡		ht		rank§	
Name	PI number	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96
		%				cm			
Ariane		87	0	6		25		1	2
Arny	524126	40	0	8		30		15	2
Beatall	522755	59	0	4		33		7	2
Belorusskij-1	486372	20	0	8		36		24	2
Berezka	486371	60	0	5		30		6	2
Bjelo Katjacs	289101	25	0	10		23		21	2
Cert. Ariane		50	0	7		30		11	2
Cert. Viking		0	0					33	2
Cirrus	522837	9	0	10		28		27	2
Concurrent	523319	33	0	10		23		16	2
Crista-Fiber	524255	24	0	8		30		22	2
Emeraude	524374	44	0	5		38		13	2

Table 3.1. (continued)

Name	PI number	survival		branching‡		ht		rank§	
		1994-95	1995-96	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96
		%				cm			
Emeraude	523782	0	0					33	2
Fakel	486380	3	0	10		25		32	2
Fivel	523433	8	0	10		20		28	2
Formosa	523220	50	0	8		36		11	2
Herra	522386	60	0	8		33		6	2
Hollandia	523222	52	0	4		30		10	2
Hyslop Cascade		66	0	6		41		4	2
Jade	523783	25	0	10		25		21	2
JWS	522836	63	0	8		33		5	2
K-6	486375	14	0	10		20		26	2
Kometa	486374	32	0	8		30		17	2
Larkana	426833	54	0	7		28		9	2

Table 3.1. (continued)

Name	PI number	survival		branching‡		ht		rank§	
		1994-95	1995-96	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96
		%				cm			
LCSD-200	311747	43	0	10		23		14	2
Linore†		63	14	3	7	30	25	5	1
Liral Prince	524214	5	0	10		10		30	2
Lisa	524371	0	0					33	2
Maupun	523452	0	0					33	2
Mogilevskij	486381	26	0	10		25		20	2
Penyau	283196	15	0	6		30		25	2
Rembrandt	249274	6	0	10		20		29	2
Rembrandt	524116	15	0	10		20		25	2
Scoctoss Leuchte	523463	4	0	6		25		31	2
Texala	523465	81	0	10		28		2	2
Textile flax	523466	30	0	9		30		18	2

Table 3.1. (continued)

		survival		branching‡		ht		rank§	
Name	PI number	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96
		%				cm			
Triumph	523470	0	0					33	2
Viking		68	0	4		30		3	2
Wiera	523305	55	0	10		28		8	2
Wiera 5 NN	320172	0	0					33	2
	523352	0	0					33	2
	523351	0	0					33	2
	522591	15	0	10		15		25	2
	240339	0	0					33	2
	523316	47	0	8		36		12	2

Table 3.1. (continued)

		survival		branching‡		ht		rank§	
Name	PI number	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96	1994-95	1995-96
		%				cm			
	524381	0	0					33	2
	523349	15	0	10		30		25	2
	524376	27	0	10		30		19	2
	523835	54	0	8		30		9	2

† check variety
‡ 1 = high degree, 10 = low degree of branching.
§ rank according to % survival.

Table 3.2. Top ranking winter hardy flax varieties at Hyslop Farms in 1994-95 and 1995-96.

					Yield	
Variety	Country	PI number	Type	Petal color	1994-95	1995-96
					g plot^{-1}	
Ariane	France	—	fiber	blue	0	—
Texala	Hungary	523465	fiber	blue	0	—
Viking	France	—	fiber	blue	0	—
H. Cascade	USA	—	fiber	blue	0	—
Linore†	USA	—	oilseed	blue	220.8	0
JWS	N. Ireland	522836	fiber	blue	0	—
Herra	Netherlands	522386	fiber	white	0	—
Berezka	Russia	486371	fiber	blue	0	—
Beatall	N. Ireland	522755	fiber	white	0	—
Wiera	Netherlands	523305	fiber	white	0	—
Larkana	Pakistan	426833	winter oilseed	blue	0	—
—	Poland	523835	fiber	blue	0	—
Hollandia	Netherlands	523222	fiber	blue	243.4	—
Cert. Ariane	France	—	fiber	blue	0	—
Formosa	Netherlands	523220	fiber	white	0	—
—	Netherlands	523316	fiber	white	116.6	—
—	France	523243	fiber	blue	0	—
Emeraude	France	524374	fiber	white	189.3	—

† winter hardy flax cv developed at Hyslop Farms in 1949.

branching (< 8) ranked the highest in agreement with Calhoun (1964, unpublished). In addition, three of the cultivars producing measureable yields outcompeted other species because they exhibited high degrees of branching (3 to 5). Although, one cultivar which rated 8 produced a measurable biomass, but the yield was much lower than the other three cultivars.

Height of the top 18 cultivars averaged 32 cm ranging from 25-41 cm. Height of the remaining cultivars averaged 21 cm ranging from 10-36 cm. The average height of the four cultivars producing measurable yields was 33 cm.

Blue and white flowered cultivars were both likely to be winter hardy. 57% of the blue and 50% of the white cultivars reached the top eighteen, while 0% of the lavender cultivars were winter hardy.

The oilseed types tested did not perform as well as Linore. The winter oilseed, Larkana, ranked 11 in the top 18 in the first winter, but did not survive the second winter. The other two cultivars from North Dakota, USA performed poorly. Linore was the only winter hardy oilseed cultivar in both winters.

Conclusion

A number of conclusions can be drawn from the results of this trial:

1. Cultivars from cool marine climates are the most likely winter hardy fiber flax cultivars.
2. Cultivars with a high degree of branching may be sources for breeding material .
3. Tall cultivars are desirable to produce high yields.

4. Blue and white flowered cultivars are potentially winter hardy.

5. Linore serves as a baseline for future winter hardiness trials.

Further research is needed to select a reliable winter fiber flax cultivar. More fiber flax cultivars from cool marine climates will have to be screened. The most productive cultivars with a high degree of branching including Hollandia, Emeraude, Viking, and Beatall need further testing. These cultivars could be good candidates for a cross with Linore.

References

Dempsey, J.M., 1975. Flax. p. 3-45. *In* Fiber plants. University Presses of Florida, Gainsville.

Fouilloux, G., 1988. Breeding flax methods. p. 14-25. *In* G. Marshall (ed.) Flax: breeding and utilization. Kluwer Academic Publ., Boston.

Franck, R.R., 1992. The history and present position of linen. p. 1-9. *In* H.S. Shekhar Sharma (ed.) The biology and processing of flax. M Publications, Belfast.

Palleson, B.E., 1995. The quality of combine-harvested fibre flax for industrial purposes depends on the degree of retting. Industr. Crops Products 5: 61-85.

CONCLUSION

We concluded that flax should be sown from the last week of March through the first week in April to obtain optimum yields, and stand densities. This planting window is similar to areas along the English Channel in Belgium, France, The Netherlands, and some districts in N. Ireland. A typical fiber flax crop planted in the last week of March in the Willamette Valley will be pulled in the second week of July and become retted by the first week of October. The crop will require 75 kg ha^{-1} N to produce around 4300 kg ha^{-1} of fiber. The development of an earlier cultivar that retts more quickly will allow earlier pulling to take advantage of late spring rains to promote retting before dry summer weather halts the retting process. Evidence suggests that separation of the cuticular layer from the cortex may be accelerated by a slight crushing of the stem. The stems retted more quickly where they were squeezed between the belts during mechanical pulling of the crop. The addition of a conditioning crusher like the one used for hay conditioning may allow faster retting of the crop. Some pulling machines have a root end crusher which could be redesigned to crush the entire stem.

Further research will have to be undertaken to select a reliable winter fiber flax variety. More fiber flax varieties from cool marine climates will have to be screened. The most productive varieties with a high degree of branching including Hollandia, Emeraude, Viking, and Beatall need further testing. These cultivars could be good candidates for a cross with Linore.

BIBLIOGRAPHY

Anonymous. 1961. The growing and harvesting of flax.. Ministry of Agriculture Leaflet 94. Stormont, Belfast.

Archibald, L.B. 1992. Quality in flax fibre. p. 297-309. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Berger, J. 1969. Flax. p. 209-215. *In* The world's major fibre crops their cultivation and manuring. Centre D'Etude de l'Azote, Zurich.

Chin Lu, K. 1953. Objective methods for determining end-point in flax retting. Ph. D. thesis, Oregon State Univ.

Cooke, G.W., and R.G. Warren. 1959. Manuring experiments on flax. Empire J. of Exp. Agric. 27:171-186.

Couchman, J.F. 1944. The effect of straw maturity on the chemical composition of flax straw and fibre. J. Counc. Sci. Ind. Res. (Aust.) 17:139-143.

Dastur, R.H., and J.G. Bhatt. 1963. The uptake and distribution of nutrients by linseed plants (*Linum usitatissimum* L.) susceptible and resistant to Fusarium Wilt. Ind. J. of Agric. Sci. 35:186-195.

Dempsey, J.M. 1975. Flax. p. 3-45. *In* Fiber crops. Univ. Presses of Florida, Gainsville.

Dewilde, B. 1987. Flax in Flanders throughout the centuries. Lanoo, Tielt, Belgium.

Dorst, J.C. 1953. Does the present trend to select for resistance to lodging in flax involve dangers of a loss in quality ?. Euphytica 2:96-100.

Easson, D.L. 1988. The quality of flax and linseed. p. 156-161. *In* G. Marshall (ed.) Flax: Breeding and utilization. Proc. EEC Flax Workshop, Brussels, Belgium. 4-5 May, 1988. Kluwer Acad. Publ., Boston.

Easson, D.L., and F.N.L. Long. 1992. The effect of time of sowing, seed rate and nitrogen level on the fibre yield and quality of flax (*Linum usitatissimum* L.). Irish J. of Agric. and Food Res. 31:163-172.

Essautier, M. 1969. Compte rendu. (In French). p. 27. *In* Institut Technique Agricole du Paris.

Eyre, J.V., and C.R. Nodder. 1924. An experimental study of flax retting. J. of the Textile Inst. 15:18.

Fouilloux, G., 1988. Breeding flax methods. p. 14-25. *In* G. Marshall (ed.) Flax: breeding and utilization. Kluwer Academic Publ., Boston.

Franck, R.R., 1992. The history and present position of linen. p. 1-9. *In* H.S. Shekhar Sharma (ed.) The biology and processing of flax. M Publications, Belfast.

Gad, A.Y., and M. El-Farouk. 1978. Influence of seeding rates and nitrogen levels on yield and some technological characters of flax. Agric. Res. Rev. 56:79-91.

Gros, A. 1967. Lin. (In French). p. 301. *In* Engrais guide pratique de la ferilisation, 6th ed. La Maison Rustique, Paris.

Hamdi, H., M.E. Ibrahim, and S.A. Foda. 1971. Fertilization of flax for oil and fibre production. U.A.R. J. Soil Sci. 11:285-296.

Hocking, P.J., P.J. Randall, and A. Pinkerton. 1989. Mineral nutrition of linseed and fiber flax. Adv. in Agron. 41:221-296.

Lewis, A.H. 1943. The uptake of nutrients by flax. Irish J. of Agric. and Food Res. 31:169-173.

Long, F.N.J., D.L. Easson, and J.P. Frost. 1988. Laboratory determination of fibre content and quality in flax. Record of Agric. Res. 36:27-36.

Maddens, K. 1976. Comparison of nitrogen fertilizers in fibre flax. In Dutch). Provinciaal Onderzoek en Voorlichingscentrum voor Land-en Tuinbouw, 169.

Menoux, Y., E. Katz, A. Essautier, and S. de Parvaux. 1982. Resistance a la verse du lin textile: influence du milieu et criteres de selection proposes. (In French). Agronomie 2:173-180.

Mikhailova, A.M. 1975. The effect of fertilizers on the quality of fibre flax. Field Crop Abstr. 29:8984.

Milthorpe, F.L. 1945. Fibre development of flax in relation to water supply and light intensity. Ann. of Bot., N.S. 9:995-997.

Nayital, S.C., and C.M. Singh. 1984. Effect of crop establishment, seed rates, and nitrogen fertilization on yield, quality, and economics of linseed in north-western Himalayas. Indian J. Agric. Sci. 54:621-698.

Neenam, M., and J. Devereux. 1973. Some recent researches on the growing of fibre flax. Sci. Proc., Royal Dublin Soc. B:201-221.

O'Connor, B.J., and L.V. Gusta. 1994. Effect of low temperature and seeding depth on the germination and emergence of seven flax (*Linum usitatissimum* L.) cultivars. Can. J. Plant Sci. 74:247-253.

Palleson, B.E., 1995. The quality of combine-harvested fibre flax for industrial purposes depends on the degree of retting. Industr. Crops Products 5:61-85.

Robinson, B.B. 1931. The time to harvest fiber flax. USDA Tech. Bull. 236. U.S. Gov. Print. Office, Washington, D.C.

SAS. 1992. SAS technical report P-229. p.289-370. *In* SAS/STAT software: changes and enhancements. Release 6.07. SAS, Cary, North Carolina

Sharma, H.S.S. 1986. Effect of glyphosate treatment on lignification of fibres of some flax cultivars. *In* Tests of Agrochem. and cv., (7). Ann. of App. Biol. 108:114-115.

Sharma, H.S.S., and C. Gilmore. 1988. An improved method for determining the caustic weight loss of flax fibre. J. Text. Inst. 80:285-286.

Sultana, C. 1983. The cultivation of fibre flax. Outlook on Agric. 12:104-110.

Sultana, C. 1988. Constraints and difficulties in harvest according to the ultimate use of the fibre and retting process. p. 93-106. *In* G. Marshall (ed.) Flax: Breeding and utilization. Proc. EEC Flax Workshop, Brussels, Belgium. 4-5 May, 1988. Kluwer Acad. Publ., Boston.

Sultana, C. 1992. Growing and harvesting of flax. p. 83-109. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Turner, A.J. 1954. Quality in flax. Linen Industry Research Institute, Lampeg, Lisburn, Co. Antrim, N. Ireland.

Van Langenhove, L., and J.P. Bruggeman. 1992. Methods of fiber analysis. p. 311-327. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Van Sumere, C.F. 1992. Retting of flax with special reference to enzyme-retting. p. 157-198. *In* H.S.S. Sharma, and C.F. Van Sumere (ed.) The biology and processing of flax. M publ., Belfast.

Wallace, T. 1953. Visual symptoms of deficiencies in crops. p. 69. *In* The diagnosis of mineral deficiencies in plants. Chemical Publ. Co., Inc., New York, N.Y.

APPENDIX

Table 1. Analysis of variance for effect of planting date on straw yield of 'Ariane' fiber flax at Hyslop Field Laboratory, Corvallis, OR in 1995.

Source	df	SS	MS	F	P-value
Total	11	58807800			
Block	3	4586330	1528780	2.3	NS
Date	2	50201100	25100600	37046.0	**
Error	6.0	4020340	670056		

Table 2. Analysis of variance for effect of planting date on plant count of 'Ariane' fiber flax at Hyslop Field Laboratory, Corvallis, OR in 1995.

Source	df	SS	MS	F	P-value
Total	11	1276900.0			
Block	3	24633.3	8211.1	0.58	NS
Date	2	1167350.0	583675.0	41.24	**
Error	6	84916.7	14152.8		

Table 3. Analysis of variance for effect of planting date on plant height of 'Ariane' fiber flax at Hyslop Field Laboratory, Corvallis, OR in 1995.

Source	df	SS	MS	F	P-value
Total	11	300.11			
Block	3	18.23	6.08	0.72	NS
Date	2	231.41	115.70	13.75	**
Error	6	50.47	8.41		